# DIELECTRIC ROTMAN LENS ALTERNATIVES FOR BROADBAND MULTIPLE BEAM ANTENNAS IN MULTI-FUNCTION RF APPLICATIONS

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## ABSTRACT

The U.S. Army Research Laboratory (ARL) is currently pursuing key technologies for the integration of a low-cost communications and radar system that allows performing multiple functionalities with a single system and an antenna. These radar and communication functions include target acquisition, combat identification, weapons guidance, secure point-to-point communications, active protection, networks for situational awareness, and signal intercept. Antennas capable of supporting multiple simultaneous beams that can be scanned over a wide range are desired as part of this objective. Furthermore, these objectives need to be satisfied over a broad band to support multiple functionalities. This paper discusses some of the developments on a printed Rotman lens design in order to achieve these objectives.

## 1. INTRODUCTION

A future goal of the U.S. Army is to have a new generation of highly mobile force, which is easily deployable and can survive in adverse conditions. In order to achieve this goal the weight of equipment needs to be reduced without any sacrifice in safety for the soldier. Currently, many different systems to perform functions such as target acquisition, combat identification, weapons guidance, secure point-to-point communications, active protection, networks for situational awareness, and signal intercept are performed separately adding bulk to the vehicle. U.S. Army Research Laboratory is pursuing this goal under the Multi-function RF (MFRF) program by integrating these functionalities with a single system and a common aperture. A prototype for such an integrated system has been completed, and demonstrated in a field test in Boise, Idaho (Weiss, et al., 2003). The system consists of Ka-band transmitter and receiver modules. Patch array antennas fed by a cavity Rotman lens (Dahlstorm and Bayba, 2002) are used in both modules. The Rotman lens provides broadband beam scanning ability. A 45-degree scan range is covered by sixteen different beam positions provided by the Rotman lens. Two simultaneous beams can be generated and can be switched to different positions by the 2x16 pin-diode switch at the input to the system. Figure 1 shows the integrated system used in the field test.

The objective of the program described above is to replace the cavity Rotman lens with a dielectric Rotman lens in order to reduce the overall size. Also, the current design is capable of scanning only in one plane. By miniaturizing the Rotman lenses, stacking them at the output ports of the current design can make elevation scanning possible. Initial designs were carried out at Ku-band to minimize cost for the prototype design.

Two different approaches are discussed for the design of the dielectric loaded lens in the following sections. The first approach is a microstrip lens design, where the feeds and delay lines are printed on a dielectric with a conductor plate in the back. The second approach launches surface waves in a thicker dielectric medium where the conductor plate in the back is removed. Measured performance for the first approach and preliminary simulation results for the second approach have been reported before (Kilic and Weiss, 2004). Work is currently underway in building and testing the alternative approach.

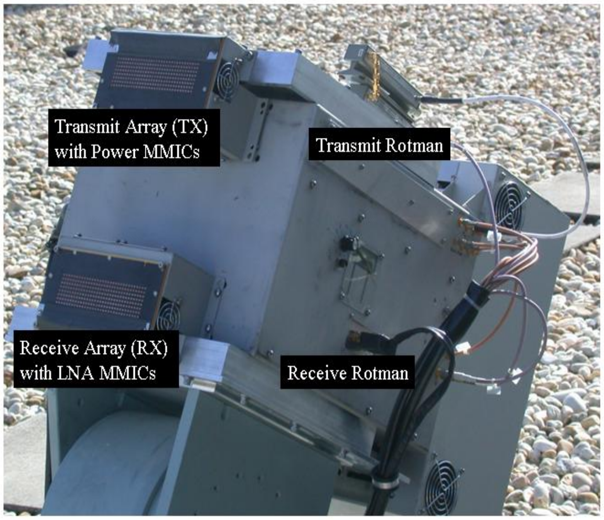


Figure 1 Prototype MFRF System

## 2. KU-BAND MICROSTRIP ROTMAN LENS DESIGN

The objective of the development is to miniaturize the two cavity Rotman lenses used in the prototype by dielectric loading. The Rotman lens is a true time delay

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structure, where the input port locations determine the scan angle. The region between the input and output ports is the parallel plate region where the fields propagate with appropriate delay in phase to allow for the desired scan (Rotman and Turner, 1963). By using a dielectric material instead of air the overall size of the lens can be reduced by a factor of $\sqrt{\varepsilon_r}$ , where $\varepsilon_r$ is the dielectric constant of the material. Based on Rotman lens geometry, a Ku-band microstrip lens was designed and built using a 20-mil thick RT5870 Duroid material, as shown in Figure 2. The lens was designed to scan over 20 degrees with 7 different beam positions. A 1x16 element patch array is connected to the output ports. The overall size of the lens is about 30 cm x35 cm.

The antenna pattern measurements were made at different input beam positions to validate the performance of the lens. Figure 3 shows the scanned beam positions at 16 GHz as the input is switched between the different ports to allow for scanning.

The high back lobes are due to the interaction of the ground plane of the microstrip patch array and the conducting feed and parallel plate structure of the lens.

Power measurements compared to a standard horn suggest that the Rotman lens integrated with the 1x16 element patch array has about 9.5 dB loss at 17 GHz. The 1x16 element patch array has a gain of 12 dBi at boresight.

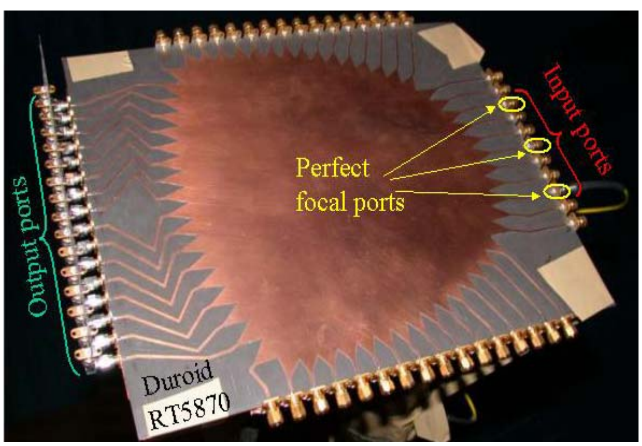


Figure 2 Ku-Band Microstrip Rotman Lens

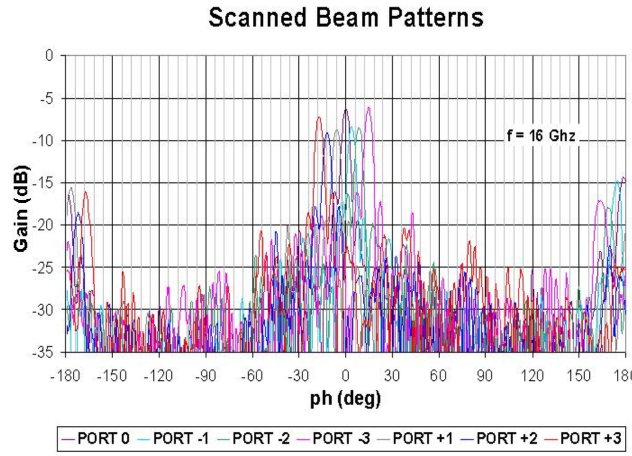


Figure 3 Antenna Pattern for Different Beam Positions of Microstrip Rotman Lens

**3. SURFACE WAVE ROTMAN LENS DESIGN**

As an alternative to the microstrip design, a dielectric lens using surface waves is being considered by ARL. This approach eliminates any need for the ground plane at the back of the lens, and significantly reduces the use of copper for the parallel plate region in the design. This is expected to reduce the copper loss in the structure.

In order to propagate surface waves efficiently, thicker dielectric substrates with higher dielectric constant are preferred. In the first prototype for the surface wave Rotman lens, RT6010 Duroid material ($\varepsilon_r$ = 10.2) is used. The surface wave is launched using an element structure similar to a Yagi-Uda element. Two slots, which act as the driver and the reflector, are used in the design. Previously, Yagi-Uda type elements with three slots, corresponding to the reflector, driver and director, have been demonstrated to effectively launch surface waves on the same Duroid substrate (Qian, et al., 1998). A drawing for two elements facing each other is shown in Figure 4.

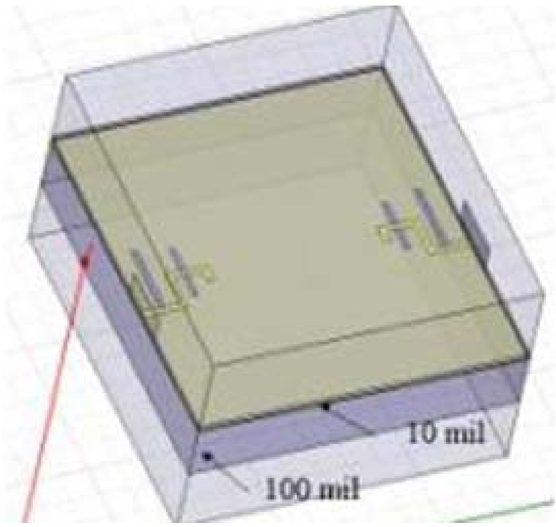


Figure 4 Two Element Surface Wave Launcher

Simulations for the two-slot element have shown that surface waves can be launched effectively in the desired direction as observed in the S-parameter curve in Figure 5.

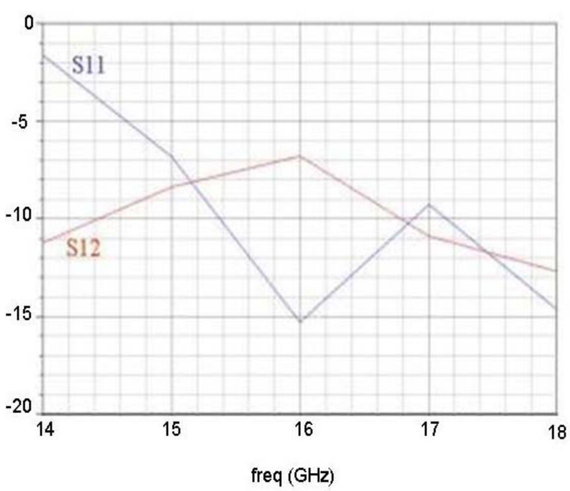


Figure 5 Simulated S-Parameter Performance for the Two Element Launcher

A drawing of the Rotman lens design using the surface wave element and the RT6010 material is shown in Figure 6. The thicknesses of the Duroid layers are chosen as 10 mils for the feed layer and 100 mils for the parallel plate region, so that only TM0 mode is excited in the structure. The lens parameters are determined so that the scan performance is identical to the microstrip lens discussed before. Since a higher dielectric is used, the overall size for this design is expected to be smaller.

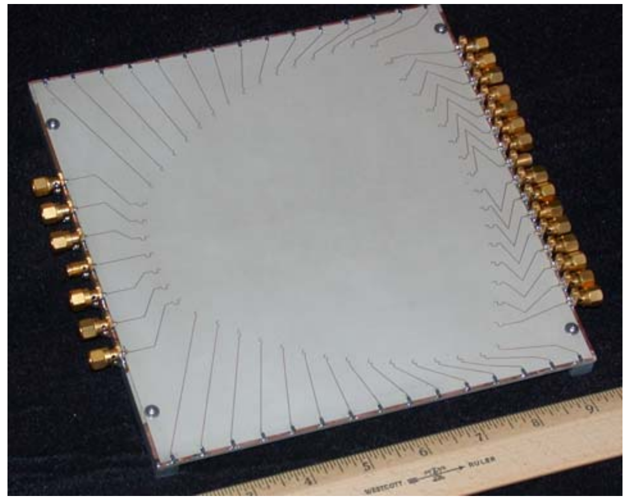

Figure 6 First Prototype Surface Wave Rotman Lens

The final board assembly is not completed at this time. Preliminary simulations were run for the central input port, which ideally corresponds to the uniform phase distribution at the output ports using Remcom's Finite Difference Time Domain software tool, XFTDT. Figure 7 shows the phase variation across one half of the output ports. The simulation results for the other half is expected to be the same based on the symmetry in the design. It is observed that the worst peak to peak phase variation across a frequency band of 14 – 18 GHz is 80 degrees at 18 GHz. It is observed that the lower frequencies perform better in terms of phase deviation.

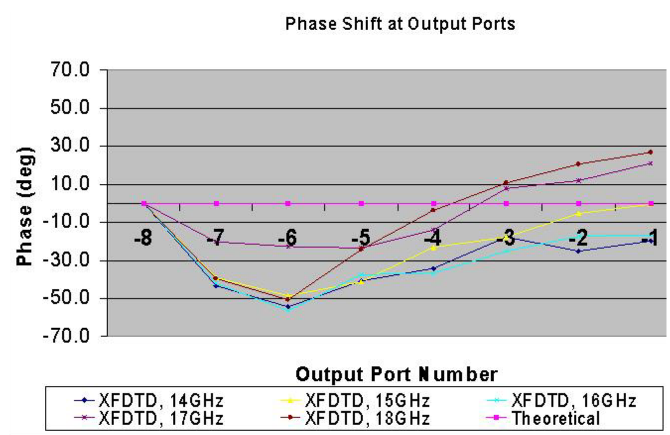


Figure 7 Simulated Phase Variations Across the Output Using XFTDT (Central Input Port Excited)

For the lens to perform well across the band the amplitude distribution needs to be uniform at the output ports. The amplitude distribution for the central input port is expected to be uniform. The simulations results for the amplitude distribution have been generated using XFTDT as shown in Figure 8. It is observed that the peak the peak variation in amplitude is within 5 dB for all frequencies across the band. This distribution is expected to produce a clean beam pattern in the far field.

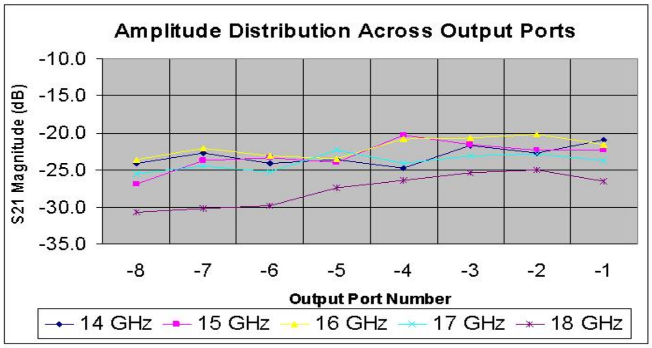


Figure 8 Simulated Amplitude Distribution Across the Output Ports Using XFDTD (Central Input Port Excited)

## CONCLUSION

A prototype Ku-band microstrip Rotman lens was designed, built and tested with a patch array antenna. The performance was consistent with theory. In an effort to further miniaturize the design and reduce the conductor loss, the ground planes in the parallel plate region of the lens are removed by introducing a surface wave launching element and utilizing the surface wave TM0 mode. The preliminary design for the element is completed and the simulations have been done for the central input port using XFTDT. The performance for the central port shows promising results both in terms of amplitude and phase; i.e. they are fairly uniform across the band. A dielectric Rotman lens utilizing the simulated surface wave approach has been designed and built, and will be tested for comparison to the microstrip lens in terms of performance.

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